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STUDIES ON THE COCCACEAE

I. PREVIOUS TAXONOMIC STUDIES CONCERNING THE GENERA OF THE COCCACEAE

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GENERAL INTRODUCTION

At the present time it is generally recognized that the spherical bacteria, altho similiar in morphology, show such a wide variation in their physiology that they are usually placed in several widely divergent groups. Four such physiologically distinct groups of cocci may be recognized, namely, (a) spherical bacteria, which derive their energy from the oxidation of simple carbon and nitrogen compounds (Nitrobacteriaceae); (b) ovoid and spherical types associated with the "sulfur bacteria" which derive their energy from oxidative processes with the cells containing free sulfur granules and bacteriopurpurin (Thiobacteriales); (c) spherical bacteria associated with the iron bacteria that are normally found surrounded by a sheath of iron or in contact with iron deposits (Chlamydobacteriales); and (d) the spherical bacteria growing on ordinary media showing a complex metabolism involving the utilization o amino-acids or carbohydrates and commonly known as the "true cocci' 'or Coccaceae. It is with this latter group of spherical bacteria that the following investigations will deal with very little reference to the other types of cocci.

The systematic relationships of the Coccaceae have for some time presented to bacteriologists a fertile field for investigation as the group includes organisms of widely different characteristics which come from a variety of sources. Bacteria definitely established as the etiological factor in certain diseases, organisms responsible for the normal souring of milk, and other equally important types are found in this group and, due to their importance from the standpoint of public health and industry, the diagnostic features and the cultural characters distinguishing the various types have made the study of this group a very important phase of bacteriological investigation.

It is the purpose of the present investigation to secure information regarding the general characteristics of certain members of this group; to review the previous work on classification and nomenclature of the Coccaceae, followed by a study of representative cultures in an effort to determine the most logical arrangement of the species into natural groups; and to arrive at a better understanding of the accuracy and adaptability of the various diagnostic tests used for the differentiation of the more important types.

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STUDIES ON THE COCCACEAE

I. PREVIOUS TAXONOMIC STUDIES CONCERNING THE GENERA OF THE COCCACEAE[1]

G. J. HUCKER

SUMMARY

A review of the history of the classification of this group shows that workers have had various conceptions as to the proper systematic relationships of the Coccaceae. The earlier literature indicates that many systematists have more or less closely associated the cocci with the green and blue-green algae, but since the introduction of modern bacteriological methods the large group of spherical bacteria have been placed in a separate family.

A study of the various names that have been used to designate genera indicates that only a small number are valid in the light of our modern rules of nomenclature.

INTRODUCTION

The taxonomic studies of the Coccaceae will be discussed from two viewpoints, the first dealing with the earlier systems of classification and the latter from the standpoint of the validity of the various generic and subgeneric names.

REVIEW OF EARLIER SYSTEMS OF CLASSIFICATION WITH SPECIAL REFERENCE TO THE COCCACEAE

Of the forms which Leeuwenhoek[2] described in 1683 from microscopic observations, a few were probably cocci. His classic drawings show several rods of various sizes and two spherical organisms which he mentions as the smallest of the types observed. Thus the cocci were among the first bacteria to be recognized as such. It was not until 1773, when O. F. Müller attempted to arrange the lower animals and plants in a logical order, that any effort was made to classify bacteria. Müller, in his original paper, which he called "A Classifica-

[1]Dissertation submitted to the Graduate School of Yale University in candidacy for the degree of doctor of philosophy.

During the course of the investigation helpful and timely criticisms have been made by Dr. L. F. Rettger, of Yale University, and Dr. R. S. Breed of this Station.

[2]See Bibliography, p. 35.

tion of the Vermes," included the infusoria, flat worms, algae, etc., with a genus called "*Monas*" in which he placed spherical bacteria and many algae. His classification was based upon morphological characters, many of which applied only to the higher forms, while the genus containing the coccus organisms was placed among the more simple types. In 1786 he classified the protozoa, and such spherical bacteria as were known were included in this group. Most of the cocci in this latter outline were again placed in the *Monas* group, while a few were grouped in a genus "*Volvox*" which was applied to various spherical algae. This confusion of bacteria, algae, and protozoa was common among the earlier workers and was due partly to the heterogeneous nature of the material with which they worked. Ordinarily, they examined stagnant water, which usually contains various kinds of organisms, such as bacteria, infusoria, and algae. Knowledge regarding these types, especially the bacteria, was so limited that no basis of differentiation was observed. The algae, however, had been previously studied to a limited extent and more was known regarding their habitat, appearance, etc.

In 1828 Ehrenberg classified the infusoria and again confused the bacteria with the lower animals. However, it is interesting to note that in Ehrenberg's classification a physiological character is used to separate the larger groups, *viz.*, certain types showing the ability to ingest such solid particles as carmine were contrasted with those which lack this ability, and the genus *Monas*, which contained the spherical bacteria, was included in the group which lacked the power to engulf solid material. In 1838 he again arranged the infusoria into a definite system and included various species of bacteria in the genus *Monas*.

Dujardin (1841) departed somewhat from the previous arrangements and contended that no spherical types existed as such. He suggested that in most cases these coccoid organisms were the swarm cells of the various algae or were short rods. With this in mind he placed all bacteria in three genera, *viz.*, *Vibrio*, *Spirillum*, and *Bacterium*, and in the latter he included some of the species which had previously been included in the genus *Monas*. In 1852, Perty carried out a similar idea and apparently allowed no place for the coccus types, but from the appended plates in which Perty indicates the forms which he has classified in the *Spirillum* and *Vibrio* group, many appear to have been cocci. However, Perty realized that bacteria were more closely related to plants than animals and was the first to

draw a sharp dividing line between these groups and to place the bacteria with other plants.

Rabenhorst (1865) and Davaine (1865) do not recognize definite groups in their systems of classification for the cocci. The former confused the filamentous algae and the bacteria and retained only three bacterial genera for the entire group.

Cohn (1854) in working with a large number of these lower plant forms of widely divergent character observed that many were covered by a gelatinous coating. The presence of this zoogleal substance appeared to him sufficiently important to warrant the grouping of all such types into the same genus which he called *Zooglea*, a group containing both algae and bacteria. He found, however, that the production of such a gelatinous covering was so common among the aquatic forms that a genus differentiated by this character alone would contain organisms of too widely divergent nature to constitute a natural group.

In 1872 Cohn again published his conception of the systematic relationships of bacteria, and for the first time placed the coccus types in a separate tribe (*Sphaerobacteria*) on an equal basis with other tribes of bacteria. He used one genus, *Micrococcus*, in this tribe in which he placed all spherical bacteria, giving it a definite description. This makes very clear his ideas regarding the systematic relationships of the round forms. In 1875, however, he attempted a more complete classification of bacteria, which was based on the idea that the various types of bacteria were degenerate types of the blue-green algae. Having in mind this close relationship between the algae and bacteria, he arranged those species of bacteria, which he supposed to be closely related to species of blue-green algae, in the same genus, with the result that many genera contained both bacteria and algae. He included the genus *Micrococcus*, which embraced nearly all of the spherical forms in this latter work; while the *Sarcinae*, or cubical packet-forming types other than those which are encapsulated by various slimy secretions, were placed in a separate group. The other genera representing spherical types belong to the green and blue-green algae. Cohn demonstrated in this classification the close relationship between the bacteria and algae.

In 1874 appeared a unique arrangement of bacteria by Billroth whose conception of these forms was somewhat different than that of his contemporaries. While Cohn and his followers were arranging bacteria into definite and well-defined genera and species, Billroth

was developing the thought that all bacteria might be variants of one species which he called "*Coccobacteria septica*." Different forms of this species were supposed to appear under the influence of various surroundings and different nutrient materials used for artificial cultivation. Fifteen forms are described as definite stages of this variable species. No species names were used for these stages as they were nothing more than descriptive terms applied to the forms which, under various conditions of growth, this mono-type might assume. Many of his terms were later used as generic names and definite binomials formed. In this list of descriptive terms used, Billroth conceded sufficient importance to one form to consider it later as a genus, called "*Ascococcus*," and named a definite species for this genus (*A. parvus*). Cocci played the principal part in Billroth's conception as rod-shaped organisms were supposed to be cocci united in chains which had failed to separate.

Billroth's ideas were not universally accepted, and five years later Trevisan (1879) arranged the cocci in his classification as follows:

Tribe Bacterieae
- Sub-tribe Eubacterieae
  - Genus *Micrococcus*, etc.
- Sub-tribe Sarcineae
  - Genus *Sarcina*
  - Genus *Chlamydatomas*, etc.

In this case the two sub-tribes were distinguished by their power to cling together in regular masses (*Sarcina*) or remain free after division and form groups of irregular colonies (*Micrococcus*). In the sub-tribe Sarcineae two genera were listed and differentiated by the presence or absence of an enveloping capsule. Trevisan, like many other systematists of this period, laid especial stress on such capsules, which indicated that he, as well as his contemporaries associated the bacteria very closely with the blue-green algae.

In 1881,[3] Winter placed all of the cocci in four genera: *Micrococcus*, *Ascococcus*, *Cohnia*, and *Sarcina*. The groups were separated by the types of colonies formed and by the way the cells were arranged into masses. A similar division was made by Flügge (1883) who, however, substituted the genus *Clathrocystis* for *Cohnia* as used by Winter. Flügge also used the phenomenon of cell grouping as a basis for distinguishing the genera.

[3]Manuscript finished in 1879, published as a paper in 1881, and appeared in Rabenhorst in 1884. Winter's outline was followed by Burrill (1882).

Zopf (1883) in his first classification did not follow the general trend of the systematists of this period, and believing that the cocci were closely related, placed them all in one genus (*Leuconostoc*). He broadened the boundaries of the genus so as to include all of the recognized bacterial types and followed the other investigators in laying particular emphasis on the presence or absence of and the type of gelatinous masses associated with the various forms listed in this genus. De Bary in 1884 carried out the same idea by placing all cocci in one genus (*Leuconostoc*), but divided the genus into species on the basis of endo- and arthrospore production.

In the same year (1883) Van Tiegham published the following classification:

Family I—Nostocaceae
Genus *Leuconostoc*
Family II—Bacteriaceae
Genus *Micrococcus*
Genus *Merista*
Genus *Sarcina*

The two families were separated on the basis of production of cysts (Nostocaceae) and formation of spores (Bacteriaceae). Van Tiegham recognized three groups of "spore-producing" cocci, *viz.*, (a) those that divide in all directions, forming large masses, were placed in the genus *Micrococcus;* (b) types that form tetrads and are in some cases covered with gelatinous covering were grouped in the genus *Merista;* and (c) the packet-forming cocci, which were placed in the genus *Sarcina*.

In 1885 Zopf again published a classification of bacteria and for the first time included all of the principal coccus types known today in one family, *Coccaceae*. In previous groupings, the spherical forms had not been regarded of sufficient importance to warrant a family name. His classification of the cocci was as follows:

Family Coccaceen
Genus *Streptococcus*
Genus *Merismopedia*
Genus *Sarcina*
Genus *Micrococcus*
Genus *Ascococcus*

Of the types producing gelatinous coverings the cocci which formed flat regular plates were placed in the genus *Merismopedia*, while the forms producing thick irregular masses were grouped in the genus

Ascococcus. The other three genera include the chain and packet forms and those types which are grouped in irregular masses. This particular arrangement of the non-gelatinous cocci into three genera was used for the first time and comes nearer to our present conception of the natural arrangement of this group than any of the earlier classifications. Migula and other systematists developed the same idea later, and in many respects this work of Zopf's may be regarded as the foundation of the generally accepted classifications of the Coccaceae. That the cocci deserve a family position as given by Zopf cannot be questioned and his arrangement appears to have been a decided step toward a rational solution of the classification of this group.

Schröter in 1886 followed Zopf's suggestion and placed all of the spherical types in one family (Coccacei). His outline is as follows:

Order Coccobacteria
Family Coccacei
Genus *Micrococcus*
Genus *Streptococcus*
Genus *Lampropedia*
Genus *Lamprocystis*
Genus *Hyalococcus*
Genus *Leucocystis*
Genus *Ascococcus*
Genus *Sarcina*
Genus *Leuconostoc*

The genera *Lampropedia*, *Lamprocystis*, *Hyalococcus*, *Leucocystis*, and *Ascococcus* included the types which produce more or less of a gelatinous coating which have since been associated with the blue-green algae and other closely related groups. The remaining genera are similar to those of Zopf.

Flügge in 1886 rearranged the cocci and proposed a new grouping, as follows:[4]

Genus *Streptococcus*
Genus *Micrococcus*
Genus *Diplococcus*
Genus *Sarcina*
Genus *Staphylococcus*

[4]Genera as listed in the graphic table, but the text also includes the Genera *Ascococcus* and *Leuconostoc*.

In this grouping of the cocci, Flügge for the first time divided the groups on a new character basis which is still commonly used and which divided the mass-forming and chain-forming types into new groups. In the case of the latter he places all of the long-chain cocci in the genus *Streptococcus*, while the short-chain types and those which appear only in pairs he separated into another group which he called *Diplococcus*. Further differentiation between these groups was made by stating that the latter produced a yellow pigment. The mass-forming types were grouped into the genera *Micrococcus* and *Staphylococcus*. The micrococci were characterized by their forming white, yellow, or red colors and by being variable in their action upon gelatin; while the staphylococci were white and yellow, liquefied gelatin, and were usually parasitic, as contrasted with the saprophytic *Micrococcus* group. The packet-forming types were placed in the genus *Sarcina*. Chromogenesis and gelatin liquefaction had not been used up to this time, and were characters which allowed more definite characterization of the groups which he established.

Trevisan (1885), surveying the general groups of bacteria, decided that bacteria could not be grouped on a morphological basis as used by many systematists previous to this time, but contended that bacteria passed thru a definite development, or life history, and he grouped the forms into three large classes as follows:

(a) Bacteria which pass thru three stages of development (filaments, rods, and cocci) and in which the filaments are typical.

(b) Bacteria which pass thru three stages of development and in which rods are typical.

(c) Bacteria which have only one morphological stage and that a coccus.

In this third group he placed all of the cocci, which he arranged as follows:

Group III. Bacteriaceae coccogenae
Genus 20 *Leuconostoc*
Genus 21 *Ascococcus*
Genus 22 *Gaffkya*
Genus 23 *Sarcina*
Genus 24 *Staphylococcus*
Genus 25 *Streptococcus*
Genus 26 *Micrococcus*

It can be seen that the gelatinous forms were still included in the coccus group and in the above outline were placed in the genera

Leuconostoc and *Ascococcus*. The non-capsulated types are arranged much as they had been by previous systematists except that a new genus (*Gaffkya*) is given which embraces types previously included in the genus *Micrococcus*. This group is characterized by having the organisms grouped in fours or tetrads. Trevisan believed that if chain formation was of sufficient importance to group such types in a genus *Streptococcus* and the formation of regular packets characterized another genus *Sarcina*, then the formation of definite tetrads, as previously described by Gaffky, should be of sufficient importance to make a third genus. The formation of this new genus results in six genera in place of the three described by Flügge, all formed on the basis of cell grouping.

In 1888 Hansgirg departed somewhat from the idea which had developed that two definite types of cocci existed, namely, the free-living and the gelatinous capsule-producing forms, and in classifying the bacteria grouped the spherical forms as follows:

C. Order Sphaerobacteria
Family Mycococcaceae
Sub-family Cystococcaceae
Genus *Hyalococcus*
Genus *Leucocystis*
Genus *Ascococcus*
Genus *Leuconostoc*
Genus *Mycothece*

In all of the genera, cysts of various kinds were supposed to be produced, and it was assumed that even the non-gelatinous types at sometime during their development produced such capsules. The genera were grouped on the basis of cell formation, whether in clumps, masses, etc.; in some cases they probably (*Mycothece*) contained many short rods.

De-Toni and Trevisan in 1889 published the most elaborate classification of the cocci which had appeared up to this time based largely on the arrangement of Trevisan (1889).

Sub-family Coccogenae
Tribe Ascococceae
Sub-tribe Euascococceae
Genus *Lamprocystis*
Genus *Ascococcus*
Genus *Bollingera*
Genus *Leucocystis*

Genus *Cenomesia*
Genus *Thiothece*
Genus *Thiocystis*
Sub-tribe Gaffkyeae
Genus *Chlamydatomus*
Genus *Gaffkya*
Sub-tribe Amoebobacterieae
Genus *Amoebobacter*
Tribe Sarcineae
Genus *Thiopolycoccus*
Genus *Sarcina*
Genus *Lampropedia*
Genus *Thiocapsa*
Genus *Pediococcus*
Tribe Streptococcaceae
Genus *Leuconostoc*
Genus *Schuetzia*
Genus *Perroncitoa*
Genus *Babesia*
Genus *Streptococcus*
Tribe Micrococceae
Genus *Neisseria*
Genus *Staphylococcus*
Genus *Micrococcus*

In this grouping the genera previously considered as important have been raised to tribal rank and each tribe further subdivided. The tribe Ascococceae includes most of the gelatinous types and the arrangement of the genera is in accordance with the type of capsule produced.

The Tribe Sarcineae included, besides the true packet-forming cocci, many forms which produced more or less regular packets under various conditions and in many cases were covered with a heavy gelatinous matrix. Another character which differentiated this tribe from the others was the fact that endospores were supposed to be produced within the cells.

The tribe Streptococcaceae which included all of the chain-forming organisms was further characterized by the production of "arthrospores either in the filaments or at the apex." This character indicates clearly that in the survey the authors had included certain filamentous types. The fourth tribe, Micrococceae was characterized

as not producing chains or endospores and only in rare cases were cysts found. This tribe contained both parasitic and saprophytic forms and the characters supposed to differentiate the genera were not clearly drawn. As a whole, the outline and arrangement of the genera was too comprehensive, as it included many types which would not be regarded as bacteria at the present time.

Ward in 1892 published an outline of the classification of bacteria, and the groupings were along the same lines that characterized many later systematic studies. Among the genera of cocci were the following:

Genus *Monococcus*
Genus *Diplococcus*
Genus *Streptococcus*
Genus *Sarcina*
Genus *Tetracoccus*

Ward divided the non-gelatinous types on the same basis as previous investigators, that is, on cell grouping beginning with single cells, and this character furnished the basis for differentiation of genera thruout the entire work. The mass-forming cocci, with irregular arrangement, which were grouped in the genera *Monococcus* and *Tetracoccus*, were not definitely characterized, but the general idea was that the solitary types were to be included in *Monococcus*, while the definite packets were grouped under *Sarcina*. No slime-forming types were recognized, and other genera, in different groups, were retained for this type of coccus.

Cornil and Babes (1890) in the same year published a similar arrangement of the cocci, *viz.:*

Group I. Micrococcus
Genus *Streptococcus*
Genus *Ascococcus*
Genus *Staphylococcus*
Genus *Sarcina*
Genus *Clathrocystis*

In this case all of the mass-forming strains, whether free-living or parasitic, were grouped under *Staphylococcus*. This was not in accord with the original description or the conception of this group up to this time and marks the first, if not the only, definition of this genus so as to include saprophytic forms. The other genera containing the non-gelatinous types are similar to those of other systematists, while Cornil and Babes preferred to group the gelatinous cocci in one genus, *Ascococcus*.

Up to this time the cocci of the non-gelatinous types had been generally placed in three or four genera and systematists had varied the nomenclature to suit their own purposes. The chain-forming cocci which were called streptococci, other than those which formed a gelatinous capsule, had only been subdivided in one case and no attempt had been made to recognize two groups on the basis of length of chain or number of units in the chains. Baumgarten (1890) concluded that the organisms described by Weichselbaum and others were sufficiently different from the usual *Streptococcus* type to adopt the generic term *Diplokokkus* which he used in 1890 in his systematic studies on bacteria following the idea used earlier by Flügge. His classification of the cocci was as follows:

Genus *Kokkus*
- Subgenus *Diplokokkus*
- Subgenus *Streptokokkus*
- Subgenus *Merista* or *Merismopedia*
- Subgenus *Sarcina*
- Subgenus *Mikrokokkus*

Other than the including of the diplococci in a separate group the striking point of this outline is the fact that the spherical types as a class are reduced to generic rank, while the various groups of cocci are considered as subgenera. This idea was never generally accepted, tho previously several systematists had given it some consideration. The discovery of such large numbers of related spherical forms had shown that the spherical types deserved to be considered as a class. Baumgarten agrees with Cornil and Babes in placing all the mass-forming cocci in a single genus, but selects the term *Micrococcus* for the group. The slime-forming types are grouped in one genus with the option of *Merista* or *Merismopedia* as names.

Hueppe in 1891 recognized only four groups of cocci, three of which (non-gelatinous types) were the chain-forming group (*Streptokokkus*), the packet-forming group (*Sarcina*), and the types which grow in irregular masses (*Mikrokokkus*). Spore production and the formation of zoogleal mass furnished a basis for division into smaller groups.

Ludwig in 1892 differed somewhat from the current opinions regarding the arrangement of the cocci. His classification included the following genera:

Genus *Micrococcus*
Genus *Diplococcus*

Genus *Streptococcus*
Genus *Hyalococcus*
Genus *Sarcina*
Genus *Leuconostoc*

Of the non-zoogleal-forming types three genera (*Micrococcus*, *Diplococcus*, *Sarcina*) appear, as in the classifications of other workers, but his conception of the genus *Streptococcus* seems to have been different. He included under this genus also the staphylococci which he called pyococci, not giving this group generic rank but considering it only as a group under the genus *Streptococcus*.

In 1893 Sternberg, the first American bacteriologist to attempt an extensive systematic arrangement of bacteria, gave the following as his classification of the cocci. This was, in general, no departure from the prevailing ideas:

Micrococci
Genus *Micrococcus*
Genus *Ascococcus*
Genus *Leuconostoc*
Genus *Streptococcus*
Genus *Merismopedia*
Genus *Sarcina*

Migula in 1894 submitted a classification of bacteria, and in this outline he departed somewhat from the conceptions of his contemporaries regarding the classification of the cocci. His outline, which in part deals with the spherical forms, is as follows:

Family Coccaceae
Genus *Streptococcus*
Genus *Micrococcus*
Genus *Sarcina*
Genus *Planococcus*
Genus *Planosarcina*

In this outline the packet-forming and the irregular mass-forming groups are subdivided on the basis of motility. The genera *Planococcus* and *Planosarcina* were supported by two or three motile species, and became so well established in Migula's ideas of the characters and arrangement of the cocci that in his later outlines motility was always used as an important diagnostic feature in other groups as well as among the Coccaceae. The other genera remain essentially the same except that no provision is made for the gelatinous forms

which Migula evidently concluded were not related closely enough to the Coccaceae to be included in this family.

The following year (1895) Migula associated, in the same system the chain-forming and non-motile irregular forms as well as the sulphur cocci. The genera were similiar to those proposed in 1894 with each subdivided into two or more sections. The following genera were again recognized, *Micrococcus*, *Streptococcus*, *Sarcina*, *Planococcus*, and *Planosarcina*.

From the above it may be concluded that he believed at this time that not all of the non-packet-formers were non-motile, and provision was made for motile forms which were united in cubical packets.

In the same year (1895) Fischer in his classification failed to make any provision for the cocci, as he contended that all spherical forms were, in some stage, elongated, and therefore should be classified with the rods.

Kruse (1896) became impressed with the idea that bacteria could not be logically arranged into definite genera and proposed the following arrangement of the groups of spherical bacteria:

Coccaceen

A. Streptococcus
    1. Saprophytic group (*Leuconostoc*)
    2. Parasitic group
        a. *Diplococcus pneumoniae* type
        b. *Streptococcus* (*Diplococcus*) *pyogenus* type

B. Merista
    1. *Tetragenus*
    2. *Diplococcus gonorrhoeae* type
    3. *Staphylococcus pyogenes* type

C. Sarcina

It may be noted that, altho he disregarded the generally accepted generic names, his general arrangement is similar to that of other systematists who designated the groups by generic names. One group, however, in this outline appears to be different from any heretofore considered, namely, saprophytic streptococci which include the chain-formers elaborating various amounts of gelatinous substances.

Lehmann and Neumann in 1896 adopted a very simple arrangement and recognized only three genera, viz., *Streptococcus*, *Sarcina*, and *Micrococcus*. Such an arrangement excluded the slime-producing

types which were placed in another group, and recognized the genera based on morphology and cell formation. Many of the more common genera, as *Staphylococcus*, were eliminated and the cocci usually included in such groups combined with other species and placed in one of the three genera given.

Fischer in 1897 concluded that the ideas regarding the cocci as put forth in his earlier paper were too schematic and in his later work he divided the cocci as follows:

Family I. Coccaceae
Sub-family A. Allococcaceae
Genus *Micrococcus*
Genus *Planococcus*
Sub-family B. Homococcaceae
Genus *Sarcina*
Genus *Planosarcina*
Genus *Pediococcus*
Genus *Streptococcus*

The cocci in the above outline are divided into the two sub-families on the basis of cell division, the Allococcaceae being the result of indefinite division forming irregular masses, while the Homococcaceae divided into regular planes forming regular masses, *viz.*, chains, packets, fours, etc. The genera were further separated on the basis of cell-formation and motility.

In 1897 Migula published a classification which was widely accepted and which has served as the basis for many of our modern keys to bacterial types, in particular one used by Chester (1901). He believed that a few of the cocci were motile, and held that motility as a character should be used to separate certain genera. However, the primary character adopted to distinguish between the genera was the nature of the cell division which is responsible for the characteristic cell groupings. His classification was as follows:

Family Coccaceae
Genus *Streptococcus*
Genus *Micrococcus*
Genus *Sarcina*
Genus *Planosarcina*
Genus *Planococcus*

Migula's classification was followed in part also by Matzuschita (1903), but the motile genera were not included and the three genera based on cell division were used to include the entire group of cocci.

In 1908 the Winslows published the most extensive study of the cocci which had appeared, up to that time. The work of the Winslows, which was a general summary of the work of Winslow and Rogers (1905 and 1906), differed from previous contributions in the fact that an extensive series of cultures was studied and the classification as presented was the result of laboratory findings. The characters used in separating the different groups and genera were chosen after a careful attempt at correlation, and the organisms were arranged in natural groups so far as these were evident. Their classification was as follows:

Family Coccaceae
- Sub-family A. Paracoccaceae
  - Genus *Diplococcus*
  - Genus *Ascococcus*
  - Genus *Streptococcus*
  - Genus *Aurococcus*
  - Genus *Albococcus*
- Sub-family B. Metacoccaceae
  - Genus *Micrococcus*
  - Genus *Sarcina*
  - Genus *Rhodococcus*

It can be seen that the three characters playing the greatest part in this arrangement are chromogenesis, cell division, and habitat. The Paracoccaceae included the parasitic types, while the Metacoccaceae included the free-living forms. The parasites were divided into five genera on the basis of cell division and pigment production, two of which were formed by dividing the old genus *Staphylococcus* into orange (*Aurococcus*) and white (*Albococcus*) groups. The second sub-family, which included the saprophytic types, was divided into three genera primarily upon cell formation and pigment production.

The Winslows in their laboratory studies found approximately the same groups of cocci recognized by other systematists who had compiled the results obtained by individual investigators, but adopted different methods and different characters for differentiation.

Flügge in 1908 arranged the cocci in much the same way as Lehmann and Neumann only two of the three families were divided into "types" upon the basis of cell division and these types correspond,

in the main, to the genera of Lehmann and Neumann. His outline was as follows:

Coccaceae
- Family Streptococcus
  - *Diplococcus* type
  - *Streptococcus* type
- Family Sarcina
- Family Micrococcus
  - *Diplococcus* type
  - *Tetragenus* type
  - *Staphylococcus* type

Conn (1909) in his earlier classification divided the cocci in much the same way as Lehmann and Neumann but later, in discussing individual groups, recognized several new genera. In none of his systematic outlines, however, were these new genera included.

The arrangement of the cocci by Orla-Jensen in 1909 is unique in that it is based primarily upon physiological characters and evolutionary conceptions. The cocci are considered as being the most primitive of all bacteria and are considered to have originated as salt water forms. These cocci are grouped physiologically with several other genera which differ morphologically but have the power to produce acid from various carbohydrates. His classification pertaining to the cocci is as follows:

Family Acidobacteriaceae
- Genus *Streptococcus*
- Genus *Micrococcus*
- Genus *Sarcina*

In the discussion he mentions other genera (*Liquidococcus*, *Solidococcus*, *Sporosarcina*, *Indolococcus*, etc.), but he uses these terms only in a descriptive sense. Altho his classification is arranged upon a physiological basis, Orla-Jensen recognizes the three main groups of cocci based on cell division. The generic terms used descriptively are usually in description of certain species possessing special or unique physiological characters.

Heim in 1911 and Löhnis in 1913 accept the types of cell division as the basis of classification and recognize the three genera *Streptococcus*, *Micrococcus*, and *Sarcina*.

In 1913 Vuillemin proposed a classification of the cocci which appeared much like the earlier outlines in which various types of blue-green algae were included with the bacteria. Eight genera are

recognized and many zooglea-forming types are included. His proposed classification is as follows:

Genus *Planococcus*
Genus *Streptococcus*
Genus *Klebsiella*
Genus *Merista*
Genus *Planomerista*
Genus *Neisseria*
Genus *Sarcina*
Genus *Planosarcina*

The characters of all of the more common genera are evident from the names. In the case of the added groups, he characterized the *Merista* genus as containing the tetrad-forming types, while the *Planomerista* group contained the motile tetrads and the genus *Klebsiella* contained the capsulated chains with more or less irregular cells.

In 1917 Buchanan submitted the following classification of the cocci:

Family Coccaceae
Tribe Streptococceae
Genus *Streptococcus*
Genus *Leuconostoc*
Genus *Diplococcus*
Genus *Neisseria*
Genus *Staphylococcus*
Tribe Micrococceae
Genus *Micrococcus*
Genus *Rhodococcus*
Genus *Sarcina*
Tribe Siderocapseae
Genus *Siderocapsa*

The cocci are divided into three tribes on the basis of physiology and habitat. The first group comprises principally the parasites, the second group the saprophytes, while the last tribe comprises a genus of spherical iron bacteria. The genera are divided on cell division, chromogenesis, and habitat. The outline corresponds in the main to the one proposed earlier by the Winslows, but differs in certain respects. Thus, the genera *Aurococcus* and *Albococcus* are combined into one genus (*Staphylococcus*) and two genera are added (*Siderocapsa* and *Neisseria*).

The Committee on Classification of Bacterial Types which was appointed by the Society of American Bacteriologists has issued two reports covering the classification of the cocci in conjunction with other groups. In the first report (Winslow, *et al.*, 1917) the cocci were arranged as follows:

Family V. Coccaceae
Tribe Streptococceae
Genus *Neisseria*
Genus *Streptococcus*
Genus *Staphylococcus*
Genus *Albococcus*
Tribe Micrococceae
Genus *Micrococcus*
Genus *Sarcina*
Genus *Rhodococcus*

It can be noted that this arrangement, as far as characters are concerned, is identical with the classification as proposed by the Winslows, but the nomenclature has been somewhat modified.

In 1920[5] the same committee (Winslow, *et al.*) published a second report in which the arrangement of the cocci was somewhat different. The previous generic groups were recognized with one new group (*Leuconostoc*) which is to embrace the zooglea-forming cocci. Another departure has been the division of the paired cocci on the basis of Gram reaction and habitat into two genera (*Diplococcus* and *Neisseria*). The second report arranged the cocci as follows:

Family IV. Coccaceae
Tribe A. Neissereae
Genus 1. *Neisseria*
Tribe B. Streptococceae
Genus 2. *Diplococcus*
Genus 3. *Leuconostoc*
Genus 4. *Streptococcus*
Genus 5. *Staphylococcus*
Tribe C. Micrococceae
Genus 6. *Micrococcus*
Genus 7. *Sarcina*
Genus 8. *Rhodococcus*

In arranging the various classifications of the cocci indicated above few of the earlier systematists, altho their ideas regarding the

[5]Bergey (1923) follows the same generic outline.

relationships of the various groups have been well substantiated in most cases, have followed the rules of nomenclature commonly accepted at the present time, while even some of the more recent investigators have continued to arrange systems of classification for the cocci and other bacteria without due regard to any of the codes governing the selection of names for the genera and species of organisms. As a consequence, bacteriological nomenclature and systematic bacteriology have fallen into such a state of confusion that only thru a careful study of the literature pertaining to the nomenclature and classification of each group and rearrangement of such information according to the modern accepted rules governing such procedures will the proper systematic relationships of various groups of organisms be established.

VALIDITY OF NAMES APPLIED TO GROUPS DESIGNATED AS GENERA AND SUB-GENERA OF THE COCCACEAE

The terms that have been used, nearly one hundred in all, to designate the various groups (genera) and sub-groups of the Coccaceae have been compiled from the systems of classification given above and from various other sources, and suggestions are offered as to their probable validity.

The validity of any given generic term is in many cases subject to the opinion of the investigator, but the writer has endeavored to follow as closely as possible the International Code for Botanical Nomenclature (1907) and the Type Basis Code as outlined by the Committee on Botanical Nomenclature of the Botanical Society of America (1920), and has given his interpretation of these rules as applied to the generic names used among the Coccaceae.

Albococcus.—Term used by Winslow and Rogers (1906, p. 544). *A. pyogenes* (Rosenbach) is given as the first of four species. Winslow and Rogers used the term *A. pyogenes* for the organism described by Rosenbach as *Staphylococcus albus*. According to Buchanan (1915, p. 536), the specific name *albus* should be retained in place of *pyogenes* for the type species. If this group of white cocci is regarded as sufficiently distinct to warrant a genus separate from the genus *Staphylococcus*, type species *S. aureus*, then the term is valid and should be listed as follows: *Albococcus*, Winslow and Rogers, 1906. Type species *A. albus* (Rosenbach) Buchanan, 1915.

Arthro-Streptococcus.—As for *Endo-Streptococcus*.

Ascococcus (Variants: *Ascokokkus*, *Askokkus*).—This term was first used by Billroth (1874, p. 12) and was the only one of his descriptive terms which he used as a binomial in connection with the specific name *parvus* (*A. parvus*). Cohn, (1875, p. 151) more definitely described the genus for which he used the term *Ascococcus* with *A. billrothii* as the only species of the genus. This species should be regarded as the type species of the genus (monotypy) according to Article 4a. of the Type Basis Code of Botanical Nomenclature which states that "if a genus included but one species when originally published this species is the type." In 1905 the genus was emended by Winslow and Rogers (1905, p. 669) with the selection of *A. mesenteroides* (Cienkowski) as the type species. In light of the fact that neither the species proposed by Billroth nor that proposed by Cohn can be identified it appears that the term is not valid and any attempt to revive it is likely to lead to confusion.

Asterococcus.—Term used by Borrell, Dujardin-Beaumetz, Jeantet, and Jouan (1910, p. 168). *A. mycoides* should be regarded as type species (monotypy). There is some question as to the morphology of the species as it seems to vary under certain conditions from a very small, almost ultramicroscopic coccus to a short rod in filaments. Buchanan (1917, p. 44) places it in the sub-tribe Hemophilinae. The term appears to be valid.

Aurococcus.—Term used by Winslow and Rogers (1906, p. 544) and *A. aureus* (Rosenbach) is the type species (monotypy). Buchanan has pointed out that this generic term is not valid in the light of Article 45 of the International Botanical Code which states that "when a genus is divided into two or more genera, the name must be kept and given to one of the principal divisions." The Winslows subdivided the genus *Staphylococcus* (Rosenbach) into two genera, *viz.*, *Aurococcus* and *Albococcus* and used the two species *S. aureus* and *S. pyogenes* of Rosenbach as typical species of the two new genera. Buchanan states that, in the light of the above rule, *Albococcus* and *Staphylococcus* are valid and *Aurococcus* is not valid.

Moreover, by the use of the older term *Staphylococcus* (Rosenbach, 1884), as emended by Winslow, *et al.* (1917, p. 558) and also emended by Buchanan (1917, p. 612), *Aurococcus* becomes invalid, as by definition it is included in the emended genus, *Staphylococcus*. In synonomy the term should be given as *Aurococcus* Winslow and Rogers, 1906.

Babesia.—Trevisan (1889, p. 29). *B. xanthopyrethica* is the first species named and should be taken as the type. Starcovici (1893, p. 1) used the term for a different organism. The term is valid only in case the type species can be reidentified and the group is found to be sufficiently distinct from the genus *Streptococcus* to warrant the formation of a new genus. Term should be given as *Babesia* Trevisan, 1889.

Betacoccus.—Term used by Orla-Jensen (1919, p. 152), with *B. arabinosaceus* and *B. bovis* as species. If the characters of these two organisms are found to be sufficiently distinct to warrant their being placed in a separate genus the term is valid.

Bollingera.—Term used by Trevisan (1889, p.26). *B. equi* is the type species (monotypy). If the type species is reidentified and characters found which warrant the formation of a new genus the term is valid. However, in light of our present knowledge it is not probable that this can or will be done.

Botryomyces.—Used by Bollinger (1887, p. 176). *B. ascoformans* (Johne) is the type species (monotypy). If sufficient evidence is found to warrant the formation of this genus the term may be valid, otherwise the term is not valid.

Botryococcus.—Used by Kitt (1888, p. 246). *B. ascoformans* (Johne) is the type species (monotypy). Term is a homonym of *Botryococcus* Kützing, an algal genus.

Carphococcus.—(Variant: Karphococcus.). Used by Hohl (1902, p. 342) with *Carph. pituitoparus* as the type species (monotypy). Term appears to be valid and should be latinized.

Cenomesia.—De-Toni and Trevisan (1889, p. 1039). *C. albida* is the first species named and should be taken as the type. Term appears to be valid if the type species can be reidentified and its characters warrant the formation of a new genus.

Chlamydatomas.—Used by Trevisan (1879, p. 137). *C. beigellii* should be taken as the type species. As for *Cenomesia*.

Clathrocystis.—Term used to include bacteria by Cohn (1875, 157). *C. roseo-persicina* is the only bacterial species given. Term proposed by Henfrey, to include blue-green algae.

Coccobacteria (Variants: *Cocco-Bacterium*, *Coccobacterium*).—Used by Billroth in 1874 in a descriptive sense. Klinger (1912, p. 186) uses the term in a generic sense with only one species, *viz.*, *C. mucosum*

anaerobicum, included. It appears that the term is not valid as the type species has never been reidentified.

Coccus.—Term used by Billroth as *coccos* (1874, p. 4) in a descriptive sense. Cohn (1875, p. 147) also used the term *coccus* but in a similar way. Fick (1887) used the term with *Coccus candicans* as the only species. This should be regarded as type (monotypy). In 1889 Nissen (1889, p. 487) again used the term in a true generic sense with *C. aquatilis* as the only species. The term is not ordinarily regarded as valid as the type species has never been reidentified.

Cohnia.—Term used by Winter (1884, p. 37). *C. roseo-persicina* (Cohn) Winter is the type species (monotypy). Term is a homonym of *Cohnia* Kunth, a genus of the Liliaceae.

Cromococcus (Spelling has later been corrected as *Chromococcus*).—Used by Bergonzini (1881, p. 149). *Chromococcus violaceous* is the type species (monotypy). Term is probably not valid as the species described is no doubt a rod and should have been included in the genus *Chromobacterium* described at the same time.

Cryptococcus.—Used by Freire (1885, p. 452). *C. xanghogenious* is the type species (monotypy). According to Sternberg the culture studied for this species was impure. Term is a homonym of *Cryptococcus* Kützing, an algal genus.

Diplococcus (Variant: *Diplokokkus*).—Used by Billroth (1874, p. 16) in a descriptive sense. Weichselbaum (1886, p. 506) first used the term in true generic sense, with a single species *D. pneumoniae*. Flügge in 1886 used the term and mentions a single species *D. albicans tardisimus*. Winslow and Rogers (1906, p. 205) emended the genus, giving more definite characters and designated *D. pneumoniae* Weichselbaum as the type species. Term was later emended by Winslow, *et al.* (1920, p. 19), with *D. pneumoniae* Weichselbaum as the type species. The term appears to be valid and should be written *Diplococcus* Weichselbaum, 1886. Type species, *D. pneumoniae*.

Diplostreptococcus.—Used by Schütz (1897, p. 494). *D. pleuro-pneumoniae* is the type species (monotypy). If the characters of the type species are found to be sufficiently different from other closely related types the term is valid and should be written *Diplostreptococcus* Schütz 1897. Type species *D. pleuro-pneumoniae*.

Endo-Streptokokkus.—Used by Hueppe (1891, p. 33) but without naming any species for the genus. Term is a hyponym as it has

never been effectively published according to the rules outlined in Section 1 of the Type Basis Code of Botanical Nomenclature.

Enterococcus.[6]—Term was used by Lewkowicz (1901, p. 635) but without naming any species. Rougentzoff again used the term (1914, p. 648). *E. saccharomyces* is the type species (monotypy). If the characters of the type species and related forms are sufficiently distinct from those of the genera *Micrococcus* and *Streptococcus* to warrant the formation of a new genus with this species as a type, the term is valid and should be written *Enterococcus* Rougentzoff. Type species *E. saccharomyces*.

Erysipelcoccus.—According to Enlows (1920) name has been ascribed by many investigators to Fehleisen (1883, p. 9). Also listed in Lipp. Med. Dictionary (1910, p. 322) as generic term. Apparently the term has never been used in true generic sense (hyponym).

Gaffkya.—Term used by Trevisan (1885, p. 106). *G. tetragena* is the type species (monotypy). The term is probably valid if the type species is sufficiently distinct from closely related forms to warrant a separate genus.

Galactococcus.—Term used by Guillebeau (1890, p. 32). *G. versicolor* is the type species (monotypy). In 1906, Conn, Stocking, and Esten (1906, p. 110) again used this term. If the cocci represented by the type species are found to be sufficiently different from the closely related types the term is valid and should be written *Galactococcus* Guillebeau, 1890. Type species *G. versicolor*.

Gliacoccos (Variants: *Gliacoccus*, *Glia-Kokkus*, *Gliakokkus*).—First used by Billroth as *Gliacoccos* (1874, p. 6), but only in descriptive sense. In 1886 Maggi (See *Jour. Bact.*,**2**, *551*) used term in similar manner. Term is not valid (hyponym).

Gonococcus.—Incorrectly ascribed to Neisser by Migula (1895, p. 16). See Enlows (1920, p. 45.) Term is synonomous with *Neisseria* Trevisan and therefore invalid.

Grippestreptokokkus.—Used by Seligman (1911, p. 81), but not in generic sense and appears not to be valid (hyponym).

Gyrococcus.—Used by Glaser and Chapman (1912, p. 223). *G. flaccidifex* is the type species (monotypy). Term is valid if characters

[6]First used by Thiercelin, *Compt. rend. Soc. Biol., Paris*, **1**, *269, 1899*.

of type species can be reidentified and if they are found sufficiently important to warrant the formation of a new genus and should be stated *Gyrococcus*, Glaser and Chapman, 1912. Type species *G. flaccidifex.*

Haematococcus (Variant: *Haematokokkus*).—Used by Babes (1889, p. 106). *H. bovis* is the type species (monotypy). Term is a homonym of *Haematococcus* Agardh, an algal genus.

Hyalococcus.—Used by Schröter (1886, p. 152). *H. pneumoniae* and *H. beigeli* are included species. Probably synonomous with *Klebsiella*, Trevišan 1885.

Hypnococcus.—Used by Bettencourt, Kopke, *et al.*, (1904, p. 55), with no type species and appears to have never been used in true generic sense (hyponym).

Indolococcus.—Term used by Orla-Jensen (1909, p. 340) but only in a descriptive sense and apparently is not valid (hyponym).

Jodococcus.—Used by Miller (1888, p. 612) as descriptive term (hyponym).

Kakkecoccus.—Used by Okata and Kokubo in 1905 as a descriptive term (hyponym).

Lactococcus.—Used by Beijerinck (1901, p. 212). *L. lactis* (Leichmann) is the type species (monotypy). Term appears to be valid and should be stated when used *Lactococcus* Beijerinck, 1901. Type species *L. lactis* (Leichmann).

Lactosarcina.—Used by Beijerinck (1908, p. 359). No type species is given and term is not valid as it was never applied in true generic sensé (hyponym).

Lampropedia.—Term used by Schröter (1886, p. 151). *L. hyalina* is the type species (monotypy). Type species appears to be an alga from the description.

Leucocystis.—Used by Schröter (1886, p. 152). *L. cellaris* is the type species (monotypy). If the type species can be reidentified and its characteristics warrant the formation of a new genus, the term is valid.

Leuconostoc.—Term was first used by Van Tieghem (1878, p. 198) and *L. mesenteroides* (Cienkowski) Van Tieghem, found in cane sugar solutions, is the type species (monotypy). This genus is probably closely related to *Ascococcus* as described by Billroth and Cohn. The term appears to be valid. It should be written *Leuconostoc* Van Tieghem, 1878. Type species *L. mesenteroides* (Cienkowski).

Liquidococcus.—Used by Orla-Jensen (1909, p. 332) in descriptive sense (hyponym).

Megacoccus.—Used by Billroth (1878, p. 6) in a descriptive sense and similarly by Miller (1886, p. 23) (hyponym).

Melococcus.—First used by Nedrigailov (1907, p. 301) to describe an organism found in the intestine of bee moths. *M. ostrajanini* is the type species (monotypy). The term is valid if the species proves sufficiently different from closely related forms to warrant the formation of a new genus. The term should be stated *Melococcus* Nedrigailov, 1907. Type species *M. ostrajanini*.

Meningococcus (Variants: *Meningokokkus*).—According to Enlows (1920), Foa and Bordono-Uffreduzzi (1888, p. 67) were the first to use the term but not in a true generic sense. In 1911, Coats and Forbes (1911, p. 242) used the term in a true generic sense. *M. intracellularis* is the type species (monotypy). Term appears to be valid and should be stated *Meningococcus* Coats and Forbes. Type species *M. intracellularis*.

Merista.—Term was used by Van Tieghem (1883, p. 1114), but no species were given. Prazmowski (1888, p. 259) used the term. *M. ureae* (Cohn) is the type species (monotypy). Term is a homonym of *Merista* Banks and Soland, 1769, which is a genus of the Spermatophytes.

Mesococcus.—Term used by Billroth (1874, p. 6) in a descriptive sense and later by Miller (1886, p. 23), but no species were indicated. Smith (1905, p. 174) mentions *Mesococcus* as a term to be rejected. The term is not valid as no species are listed in either of the initial descriptions (hyponym).

Merismopedia.—Zopf (1885, p. 51) applied the term to a group of cocci which he described as being arranged in plates, with cell division in two directions with formation of cell layers. *M. gonorrhoeae* is the type species (monotypy). Term is a homonym of *Merismopedia* (Meyen, 1828), a genus of blue-green algae.

Micrococcus (Variants: *Mikrokokkus*).—*Micrococcus* was first used by Hallier (1867, p. 108), but not in a true generic sense. His descriptions are more or less indefinite, and it is evident that he confused the bacteria with which he was working with certain stages of mold growth. He gave no type species. Cohn (1872, p. 151) definitely describes a genus to which he gives the name *Micrococcus*, and includes several species in the genus. The first of these species is *M.*

prodigiosus which properly belongs in the genus *Serratia* Bizio. (See Breed and Breed, 1924.) Another species, *M. luteus*, was described and has been designated as the type species by Buchanan (1915). The term is valid and when used should be stated *Micrococcus* Cohn, 1872. Type species *M. luteus* (Schröter) Cohn, if used to designate a genus containing both parasitic and saprophytic forms. If the genus is to represent only the saprophytic types the emendation of Winslow and Rogers (1905) should be noted.

Microsphaera.—Used by Cohn (1872 A, p. 229). *M. vaccinae* is the type species (monotypy). Term is a homonym of *Microsphaera* Léveillé, 1851, which is a genus of fungi.

Monococcus.—Used descriptively by Ward (1892).

Monas.—The term was first used by Müller (1773, p. 25, see Enlows), with *M. termo*, *M. lens*, and *M. mica* as included species. Ehrenberg emended the term (1828, p. 17), with *M. crepusculum* as the type species (monotypy). The term is not valid as a bacterial genus as the genus was originally proposed for an animal group which included some bacterial forms. The bacterial species were so poorly described as to be unidentifiable.

Myrokokkus.—Term first used by Gonnerman (1907, p. 877). *M. betae* is the type species (monotypy). Supposedly an arthrospore-producing streptococcus. If the type species is reidentified and found to be sufficiently distinct from closely related forms to warrant placing it in a new genus, the term is valid and should be stated *Myrokokkus* Gonnerman, 1907. Type species *M. betae*.

Neisseria.—Term was first used by Trevisan (1885, p. 105). *N. gonorrhoeae* is the type species (monotypy). The genus appears to be valid and should be stated *Neisseria* Trevisan, 1885. Type species *N. gonorrhoeae*.

Pediococcus (Variant: *Pediokokkus*).—First used by Balcke (1884 p. 183). Lindner later used the term and further described the organism and added two additional species. *P. cerevisiae* is the type species (monotypy). Term is valid if the type species is sufficiently different from closely related forms to warrant the formation of new genus. Should be stated *Pediococcus* Balcke, 1884. Type species *P. cerevisiae*.

Pedioplana.—Used by Wolff (1907, p. 9). *P. haeckeli* is the type species (monotypy). From the plates given it is evident that the forms described are similar to *Planococcus* and *Planosarcina*. If the type species can be reidentified, the term should probably be regarded as synonomous with one of the above genera.

Peptonococcus.—Used by Orla-Jensen (1909, p. 340) for a peptonizing lactic acid forming coccus. No type species is given and the term is apparently invalid (hyponym).

Perroncitoa.—Used by Trevisan (1889, p. 29). *P. scarlatinosa* is the type species (monotypy). The characters of the type species as given are probably unidentifiable and it appears that the term is not valid.

Planococcus.—Term was first used by Migula (1894, p. 235). *P. citreus* (Menge) Migula is the type species (monotypy). Term is valid if the characters of the type species given are of sufficient importance to warrant a new genus. Term should be written *Planococcus* Migula, 1894. Type species *P. citreus* (Menge) Migula.

Planosarcina.—Term used by Migula (1894, p. 235). *P. agilis* (Ali-Cohen) Migula is the type species (monotypy). Term is valid on same conditions as *Planococcus*. Should be written *Planosarcina* Migula, 1894. Type species *P. agilis* (Ali-Cohen) Migula.

Planomerista.—Term used by Vuillemin (1913, p. 523). *P. ventriculi* is the type species (monotypy). Insufficient description of the type species. Term is probably not valid.

Pneumococcus.—Term used by Arloing (1889, p. 430). *P. gutta-cerei*, *P. lichenoides*, and *P. flavescens* are included species. Term appears to be valid and should be stated *Pneumococcus* Arloing, 1889. Type species *P. gutta-cerei*.

Pseudodiplococcus.—Used by Bonome (1888, p. 321). *P. pneumonicus* is the type species (monotypy). Term appears to be valid and should be stated *Pseudodiplococcus* Bonome, 1888. Type species *P. pneumonicus*.

Pseudomeningococcus.—Term used by Elser and Huntoon (1909, p. 384) with no type species. Term is evidently not valid as only used in descriptive sense (hyponym).

Pseudo-sarcine.—Term used by Mazé (1903, p. 887), with no type species and term is evidently not valid (hyponym).

Rhodococcus.—Term first used by Zopf (1891, p. 28) as subgenus of *Micrococcus*. *R. erythromyxa* and *R. rhodochrous* were listed as the only species. Genus was emended by Winslow and Rogers (1906, p. 206) and *R. cinnabareus* (Flügge), *R. roseus* (Flügge), *R. fulvus* (Cohn), *R. agilis* (Ali-Cohen), *R. rosaceus* (Lindner) and *R. incarnatus* (Grüber) were included. Buchanan (1915, p. 614) used the term and stated that *R. roseus* (Flügge) Winslow was probably the type species. Winslow, *et al.* (1920, p. 208) designated *R. rhodochrous* as the type

species. The term is valid if the characters of the type species are considered sufficiently distinct from closely related types to warrant a new genus. The genus should be stated *Rhodococcus* Zopf, 1891. Type species *R. rhodochrous* Zopf by subsequent designation.

Sarcina.—Term was first used by Goodsir (1842, p. 430) to describe an organism isolated from the stomach. *S. ventriculi* is the type species (monotypy). It is described as being a plant exhibiting "no mouth, no oral appendages, no visceral sacs, and its cells, instead of having the gelatinous appearance familiar to the observer of the animal infusorials, are clear, transparent, as if empty and have that consistency of unit characteristic of vegetable structure." Hallier (1866,) stated that *S. ventriculi* Goodsir was synonomous with *M. ventriculi*, but from the plates given it is evident that the *Sarcina* cultures which he (Hallier) described were not true bacteria but algal forms. Winslow and Rogers (1905, p. 669) emended the genus giving more definite characters. The term appears to be valid and if used should be stated *Sarcina* Goodsir, 1842. Type species *S. ventriculi*, Goodsir.

Sarcinaglobulus.—Used by Poulsen (1879, p. 232). (See Enlows.) *S. punctum* is the type species (monotypy). From the description it appears that the type species may be an alga.

Solidococcus.—Term used by Orla-Jensen (1909, p. 332) only in a descriptive sense with no type species (hyponym).

Schützia.—Used by Trevisan (1889, p. 29). Three species named *viz. S. Poelsii*, *S. Laughlini*, and *S. Dissei*. The descriptions of species are so meager that it will probably be impossible to recognize them and apparently the term is not valid.

Sphaerococcus (Variant: *Sphaerokokkus*).—Term used by Marpmann (1886, p. 121). *S. lactis acidi* is the type species (monotypy). Term is a homonym of *Sphaerococcus* Agardh, 1823, an algal genus.

Sporosarcina.—Term used by Orla-Jensen (1909, p. 340) as spore-forming type of *Sarcina*. No type species given (hyponym).

Staphylococcus (Variants: *Estaphylococcus*, *Staphilococcus*, *Staphylokokkus*).—First used in descriptive sense by Ogston (1880, p. 27). Rosenbach again used the term (1884, p. 18) and used a trinomial for the organisms included, *viz.*, *S. pyogenes aureus* and *S. pyogenes albus*, when outlining their description but later in the same publication used the binomials *S. aureus* and *S. albus*. Winslow, *et al.* (1917, p. 558) emended the genus and designated *S. aureus* (Rosenbach) as

the type species. Genus appears to be valid and when used should be written *Staphylococcus* Rosenbach, 1884. Type species *S. aureus* Rosenbach. (See *Aurococcus*.)

Streptomicrococcus.—A descriptive term used by Billroth (1874, p. 11), but not in a generic sense and so is not valid (hyponym).

Streptococcus (Variants: *Estreptococcus*, *Streptokokkus*).—Term was first used by Billroth (1874, p. 10), but only in a descriptive sense. Rosenbach (1884, p. 22) used the term to represent a chain-forming genus of cocci with *S. erysipelatos* (Fehleisen) Rosenbach and *S. pyogenes* Rosenbach as species. Winslow and Rogers (1905, p. 669) emended the genus giving it more definite characters and designated *S. pyogenes* Rosenbach as the type species. Term is valid and should be stated *Streptococcus* Rosenbach, 1884. Type species *S. pyogenes* Rosenbach, 1884.

Tetracoccus (Variant: *Tetrakokkus*).—*Tetrakokkus* was first used by Klebs (1887, p. 337). *T. variolae* is the type species (monotypy). Billet used the term also but not in a generic sense and included *T. butyri* as a species of the genus. The term is valid if such characters as are embodied in the description of the species are of sufficient importance to form a new genus. The original term of *Tetrakokkus* must be latinized and the term should be written *Tetracoccus* Klebs, 1887. Type species *T. variolae*.

Tetragenus.—Term first used by Kruse (1896, p. 94), but only in a descriptive sense. Vincenzi (1897, p. 758) used *Tetragenus* as a generic term in 1897. *T. citreus* is the type species (monotypy). Altana also used the term (1909, p. 44) with *T. tardissimus* as a new species of the genus. If the characters representing the type species are considered sufficiently different from those of other closely related types, the term is valid and should be stated *Tetragenus* Vincenzi, 1897. Type species *T. citreus*.

Tetradiplococcus.—Term used by Bartoszewicz and Schwarzwasser (1908, p. 614). *T. filiformis* is the type species (monotypy). Term is valid.

Urococcus.—Term used by Miquel (1888, p. 519) to describe a urea-fermenting coccus. Term only used in a descriptive sense (hyponym). Homonym of the algal genus Urococcus Hassal, 1845.

Urosarcina.—Term used in the same way as *Urococcus* by Miquel (1888, p. 519), with no type species and appears not to be valid (hyponym).

DISCUSSION AND CONCLUSION

From the foregoing review it is evident that many systematists, especially those working previous to the introduction of modern methods of technic, have confused the spherical bacteria with the green and blue-green algae. Some workers on the contrary have believed these groups closely related and have endeavored to construct outlines to include members of both groups. Since the introduction of better methods for studying bacteria, investigators have generally agreed that the Coccaceae is a separate and distinct family and is composed of several more or less closely related genera.

More recent workers in systematic bacteriology appear to agree on the fact that there are at least three different groups of cocci, *viz.*, (a) those which divide in parallel planes forming chains of two or more units; (b) cocci which divide in two or more planes without the formation of regular cubical packets; and (c) those dividing in three planes, each at right angles to the other, forming regular cubical packets of cells. That such definite sub-groups of the Coccaceae deserve generic rank is generally accepted, but the further division of these groups or the addition of other genera have always met with criticism.

The chain-forming group has been subdivided into many genera chief among which are *Diplococcus*, characterized by being in pairs and Gram positive, and *Neisseria* similar in many respects but Gram negative. Many workers familiar with this field feel that the more or less lance-shaped *Pneumococcus* is sufficiently different to be placed in a separate genus. The division of the *Streptococcus* group, all of which divide in one plane, with certain possible exceptions, has centred around the possible type of cell division together with various cultural and serological reactions. Divisions of this important group have not met general approval.

The packet-forming types have for sometime been regarded as a distinct group, and altho related closely enough to other spherical forms to be placed in the family Coccaceae, investigators have never generally associated them with other groups.

The types which divide so as to form irregular masses have furnished a more difficult problem to the systematist due to the fact that many of this group appear to be closely related to *Streptococcus* in forming short irregular chains when freshly isolated, while others from other sources clump into groups more nearly resembling *Sarcina*.

This fact has caused many investigators to divide this group into two sub-groups, *viz.*, (a) *Micrococcus*, or the saprophytic forms, and (b) *Staphylococcus*, the parasitic types. This division has appeared artificial to many workers who have placed all cocci of this type in one group designated either as *Micrococcus* or *Staphylococcus*.

A large number of the names as applied to the various groups are found to be invalid in the light of our present codes of nomenclature, but the terms which deserve further consideration for use in designating genera of the Coccaceae are as follows: *Albococcus*, *Asterococcus*, *Diplococcus*, *Diplostreptococcus*, *Enterococcus*, *Gaffkya*, *Galactococcus*, *Gyrococcus*, *Carphococcus*, *Lactococcus*, *Leuconostoc*, *Melococcus*, *Meningococcus*, *Micrococcus*, *Myrokokkus*, *Neisseria*, *Pediococcus*, *Pedioplana*, *Planococcus*, *Planosarcina*, *Pneumococcus*, *Rhodococcus*, *Sarcina*, *Staphylococcus*, *Streptococcus*, *Tetracoccus*, *Tetragenus*, and *Tetradiplococcus*. The selection of the names for the larger groups must depend upon the genera included in the various groups. The generic names are not listed as all being valid for use in the same classification, and they may be used subject to the suggestions given under the discussion dealing with the validity of each name.

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